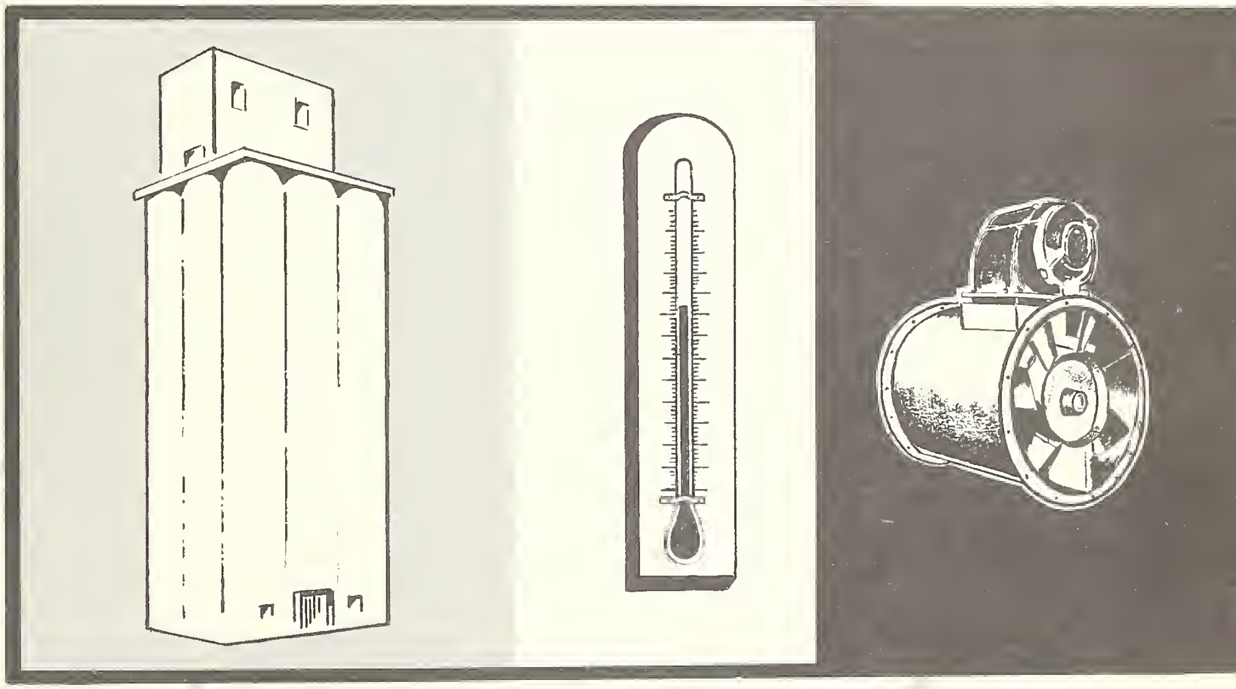
OPERATING GRAIN AERATION SYSTEMS IN THE SOUTHWEST



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Agricultural Marketing Service
U.S. DEPARTMENT OF AGRICULTURE
in cooperation with the
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PREFACE

The research on which this report is based is part of a larger project on the aeration of grain in commercial storages. The report discusses methods of operating aeration systems in Texas. It supplements the information in Marketing Research Report No. 178, "Aeration of Grain in Commercial Storages."

David L. Calderwood, agricultural engineer with the Transportation and Facilities Research Division of the Agricultural Marketing Service, and Leron E. Satterwhite and Herbert E. Schleider, formerly with the same organization, helped to conduct the research studies. Leo E. Holman, also of the Agricultural Marketing Service, was the supervisory project leader, and helped in preparing this report. Grain storage operators made their facilities available for the tests, and suppliers loaned equipment used in some of the tests.

This research was conducted in cooperation with the Texas Agricultural Experiment Station.

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OPERATING GRAIN AERATION SYSTEMS IN THE SOUTHWEST

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SUMMARY

The practice of aerating grain came into widespread use in the Southwest between 1955 and 1960. It is estimated that more than 75 percent of the 722 million bushels of Government-approved storages in Texas in 1960 were equipped with aeration systems.

Aeration is used (1) to maintain the quality of undried grain until it can be moved through the dryer; (2) to remove harvest or dryer heat; (3) to remove small amounts of moisture (1 to 2 percent); and (4) to maintain the quality of grain during storage.

Most aeration systems in the Southwest are designed to move the air from the top down through the grain and discharge it at the bottom. However, many systems are designed to move the air either downward or upward through the grain. There are some advantages and disadvantages with either method. There are also some advantages to moving the air across the bin in tall upright storages. The type of system most suitable for a given situation depends upon the purpose for which aeration is to be used, the installation and operation expense involved, and the adaptability of the storage units to a particular type of system.

The proper method of operating an aeration system depends upon the purpose for which aeration is being used as well as the prevailing weather.

When aeration is used for holding undried grain before moving it through the dryer, the fan should be operated continuously. High-moisture grain (above 16 percent) can seldom be held with aeration for periods exceeding 2 weeks without some loss in quality. The higher the moisture content of the grain, the shorter should be the holding period before drying.

If aeration is used for removing harvest or dryer heat from stored dry grain, the fan should be operated continuously until the grain temperature is approximately the same as the outdoor air temperature.

Aeration sometimes is used to reduce grain moisture by 1 or 2 percentage points to make it safe for storage. To do this the fan should be operated continuously for about 20 days, then operated only when the temperature of the outside air is 10 or more degrees cooler than the grain temperature, or whenever there is evidence of grain heating. Aeration is not recommended for fast drying. If the grain is to remain in storage less than 3 months and must meet market requirements, it should be dried by a more rapid method.

When aeration is used only for maintenance of quality of stored dry grain, the fan should be operated only when grain can be cooled without adding moisture to it. Grain temperatures should be reduced as soon as possible to between 40° and 50° F. Several aerating periods are required in the Southwest because cool outdoor temperatures seldom prevail long enough for a cooling stage[1] to be completed during a single aeration period. Each stage of the cooling should lower the grain temperature 10 to 15 degrees.

Several methods of controlling aeration fans have been used satisfactorily in the Southwest. Fans controlled manually can provide adequate cooling, but this method usually results in considerable inconvenience, loss of operating time during good aeration weather, and excessive operating time to obtain the desired grain temperature.

Time clocks provide some means of control, but they exclude much aeration during favorable weather. Time clocks require attention to insure that power failures or other interruptions do not cause unwanted operation of fans.

Conventional heating-type thermostats provide control which is superior to either manual or time-clock control.

Differential thermostats permit operation of fans when a predetermined difference in temperature between the high-limit sensing bulb and the low-limit sensing bulb is exceeded, regardless of the level of temperature. They offer the best means of controlling fans in the Southwest area, if the high-limit bulb is properly located in the grain mass.

Thermostats to prevent operation at low air temperatures are not needed in the central and southern parts of Texas; they may be necessary if grain is aerated during the late winter in the west Texas area.

Humidity controllers were used for controlling aeration fans in several tests but were not necessary for most operations.

Electricity for the fan is seldom a major cost item in the operation of an elevator. Actual cost of electricity usually runs well below 0.2 cent per bushel.

[1] See Definition of Terms, page 4.

BACKGROUND INFORMATION

This report is one of four regional reports that have been prepared to provide information on methods of operating aeration systems. Similar reports are available for the Southeast, the Corn Belt, and the Hard Winter Wheat Area.

This report is based on aeration tests conducted in a number of locations in Texas from 1954 through 1959. Most of the data were obtained from tests made in the Gulf Coast area where warm temperatures and high humidity prevail. Results from these tests provide the basis for the information and recommendations for controlling aeration fans, operating schedules, direction of airflow, and the cost of operating aeration systems given in this report.

Marketing Research Report No. 178, "Aeration of Grain in Commercial Storages," gives information on the design, selection, and installation of aeration systems together with general information on operating procedures and ownership and operating costs. It also reports findings on direction of airflow during aeration, satisfactory grain temperatures, cooling zones, time required to cool grain, and cooling resulting from the evaporation of moisture during aeration. Results of these findings are not repeated in detail in this report.

DEFINITION OF TERMS

Terms generally familiar to the grain trade are not defined or explained. Certain terms which may be unfamiliar to some readers, and terms used in a special sense, are defined below:

Aeration.—The moving of air through stored grain at low airflow rates (generally between $\frac{1}{20}$ and $\frac{1}{10}$ cfm per bushel), for purposes other than drying, to maintain or improve its value.

Duct.—A chamber in the grain through which air is moved into or out of the grain. This chamber is commonly referred to as a collector, tunnel, aeration duct, air duct, plenum chamber, etc.

Supply pipe.—A tight-walled pipe or tube for conveying air between the fan and duct.

cfm.—Cubic feet of air per minute, the designation for the volume of air being moved.

Upright storage.—Any storage where the height is greater than the diameter or width. This type of storage also is commonly referred to as a deep bin, tank, silo, cell, or vertical storage.

Flat storage.—Any storage where the height is less than the diameter or width. These storages also are referred to as horizontal storages.

Grain.—All cereal grains, oil seeds, and other seeds unless otherwise designated.

Cooling zone.—That portion of the grain mass in a storage where the temperature is falling during aeration.

Cooling stage.—The process of moving a cooling zone entirely through a lot of stored grain.

Peak-loading.—Filling flat storages so that grain accumulates to a greater depth at the centerline or under the peak of the building than at the sidewalls. The grain is allowed to assume the angle of repose from the peak to the sidewalls.

Equilibrium moisture content.—Grain moisture content which is in equilibrium with air at a given relative humidity.

DESCRIPTION OF AERATION TESTS

The Texas tests were made in upright storages of various depths, flat storage buildings, and oil tanks. Size of aeration systems ranged from $\frac{1}{10}$-horsepower units to 100-horsepower units. Several methods of aeration as well as methods of controlling the fan were studied. Data were obtained on movement of air down through the grain, up through the grain, and across the bin. Grain temperatures were taken with thermocouple systems. Samples were tested for moisture content, germination, free fatty acid, and official grade to determine the effects of different storage conditions on the quality of the grain. Airflow measurements were made using Shedd's data [2] and were compared to airflow measurements made with calibrated nozzles and velocity meters. Standard air measuring instruments were used. Continuous weather records were made with recording instruments and checked against U.S. Weather Bureau data.

[2] Shedd, C. K. Resistance of Grains and Seeds to Airflow. Agr. Engin. 34: 616–619. 1953.

UPRIGHT STORAGE

Mathis, Texas

Welded steel tanks with cone bottoms and roofs (fig. 1) were used for studies at this location. Each tank was 34 feet in diameter and 48 feet tall and had a capacity of 38,000 bushels. The grain was peak-loaded (see Definition of Terms) and each tank was equipped with an aeration system. Tests were made to determine the time required to cool grain when air was supplied at rates of 1/20, 1/15, and 1/10 cfm per bushel. Fans were controlled with conventional heating-type thermostats, time clocks, and differential thermostats.

BN-14746

FIGURE 1.—Upright storages with cone bottoms and roofs, Mathis, Texas. Each tank has a capacity of 38,000 bushels of grain and is equipped with an aeration system.

Beeville, Texas

Studies were made in two flat-bottomed bins (fig. 2) each 32 feet in diameter and 40 feet high. The capacity of each bin was approximately 26,000 bushels. The primary purpose of these tests was to study the spacing of aeration ducts in large tanks. However, studies were also made to determine the time required to cool grain at different airflow rates and to develop satisfactory operating schedules. An aeration system was installed in each bin. Thermostats and humidistats controlled the aeration fans. Airflow rates of 1/15 and 1/10 cfm per bushel were used.

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FIGURE 2.—Upright storages with flat bottoms, Beeville, Texas. Each bin holds about 26,000 bushels of grain and has its own aeration system.

Robstown, Texas

Two flat-bottomed bins, each 32 feet in diameter and 48 feet tall (fig. 3), were used in studies at Robstown. The capacity of each bin was 32,000 bushels. A multiple system aerated seven similar bins simultaneously. Fans were controlled manually, and the air was moved vertically downward through the grain. The study provided information on aeration in upright storage with air supplied at a rate of 1/20 cfm per bushel.

BN–14749

FIGURE 3.—Upright storages with one aeration system for seven bins, Robstown, Texas. Each bin holds 32,000 bushels.

BN–14751

FIGURE 4.—Upright storages with multiple aeration system, Agua Dulce, Texas. Capacity of each bin is 12,500 bushels.

Agua Dulce, Texas

Observations were made on the operation of a multiple aeration system (fig. 4) in two bins, each 22 feet in diameter and 40 feet high with a capacity of 12,500 bushels. Separate tests were run with upward movement and with downward movement of air through the grain and with thermostats and manual controls. The time required to cool grain with an airflow rate of 1/10 cfm per bushel was observed.

Temple, Texas

Eight flat-bottomed, bolted steel tanks, each 22 feet in diameter and 65 feet high, with a total capacity of 160,000 bushels, were used to study the feasibility of placing the aeration fan on top of the bins. Ten-foot sections of half-round, corrugated, perforated duct, 14 inches in diameter, were placed vertically on quadrants on the inside wall near the bottom of the tanks. The fan was placed on top of a tank near the middle of the group, and a manifold was run between the two rows of tanks (fig. 5). A supply pipe with a gate valve connects the manifold to each tank just below the roof of the tank. The air was forced down through the grain and into the aeration ducts near the bottom. Eight-inch diameter openings in the wall (behind the ducts) allowed the air to escape to the outside. The fan unit was controlled manually and provided an airflow rate of $\frac{1}{10}$ cfm per bushel through four tanks.

BN–14750

FIGURE 5.—Manifold installed between two rows of tanks, Temple, Texas. Aeration fan was placed above one of the tanks, and the manifold and supply pipes carried the air to the individual tanks.

FLAT STORAGE

Mathis, Texas

Tests were run in 13 bins, each being 18 feet in diameter and 16 feet tall (fig. 6), with a capacity of approximately 3,300 bushels. Comparisons were made of the effectiveness of different airflow rates and methods of controlling fans. Downward as well as upward movement of air through the stored grain was studied. Conventional heating-type thermostats, differential thermostats, time clocks, and humidity controllers were used for controlling the fan. A total of 30,000 bushels of grain was used each year for these tests.

BN-14747

FIGURE 6.—Each of the flat storage bins (18 feet in diameter and 16 feet high) in the background holds 3,300 bushels of grain. Thirteen of this group of 117 bins, in Mathis, Texas, were used for aeration studies.

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Bryan, Texas

An 80- by 216-foot flat storage building with a roof slope of 8 inches in 12 inches and 16-foot sidewalls (fig. 7) was used to study the design of aeration systems for peak-loaded grain. The capacity of the building was about 300,000 bushels. The main duct of the aeration system was a concrete tunnel which ran lengthwise under the floor at the center of the building. Metal ducts were run across the building on 18-foot centers and were reduced in size under the shallower depths of grain. Two fans, one on each end of the concrete tunnel, were used to pull the air down through the grain. The system provided $\frac{1}{10}$ cfm of air per bushel at the greatest depth and slightly more through the shallower depths of grain. The fans were manually controlled.

BN-14752

FIGURE 7.—This flat storage building in Bryan, Texas, has a concrete tunnel running lengthwise of the building for aeration. Metal ducts run from this main duct to the sidewalls. Two fans, one at each end of the main duct, pull the air down through the grain.

Fort Worth, Texas

An aerated building 200 feet wide and 800 feet long with the grain 55 feet deep in the center and 4 feet at the sidewall was studied. The capacity of the building was approximately 3 million bushels. The aeration system consisted of two 100-horsepower fan units connected, one on each end, to an 8- by 6-foot tunnel running lengthwise under the center of the building and connected to half-round aeration ducts which ran across the building on 18-foot centers. These ducts were reduced in steps from 30 inches in diameter under the deepest grain to 10 inches in diameter under the shallowest grain. Duct sections with solid walls were interspersed with sections with perforated walls under the shallower grain depths to make the distribution of air more uniform. The system supplied air at approximately 1/20 cfm per bushel. The fans were started and stopped manually.

Temple, Texas

Two oil tanks, each 96 feet in diameter and 30 feet tall, and with a capacity of about 170,000 bushels, were used to study aeration in large tanks. Aeration duct spacing and operating procedures needed with such designs were studied. The aeration system consisted of three 30-inch-diameter half-round ducts running across the tank and spaced 30 feet apart, beginning at the center of the tank, and a 3-horsepower tube axial fan unit on each end of the three ducts (fig. 8). The system supplied air at the rate of 1/10 cfm per bushel. The fan motors were controlled by both high- and low-limit thermostats and humidistats.

BN–14748

FIGURE 8.—Three 30-inch-diameter half-round ducts with a 3-horsepower tube axial fan on each end provide aeration in this oil tank.

HOW GRAIN COOLS

COOLING ZONES

When cool air is moved through a warm mass of grain, a cooling zone is formed. This zone forms first in the grain nearest the point where the air enters the grain mass. As aeration progresses, the zone moves through the grain in the direction the air is moving (fig. 9). Behind the zone the grain approaches the temperature of the entering air. In front of the cooling zone the grain remains at the initial temperature of the grain. Several hours or days may be required to move the zone through the grain mass, depending upon the airflow rate and the hours the weather is suitable for cooling the grain without adding moisture.

COOLING AS A RESULT OF EVAPORATION

When air is moved through grain there is an exchange of both heat and moisture until the air and grain come to equilibrium. Usually the temperature of the air and of the grain becomes the same after the air has moved only a few feet into the grain mass. If the relative humidity of the air is higher than the equilibrium moisture content of the grain, moisture from the air transfers slowly to the grain. If the equilibrium moisture content of the grain is above that of the air, moisture is transferred from the grain to the air and some drying takes place as the air moves through the grain. For most aeration practices in the

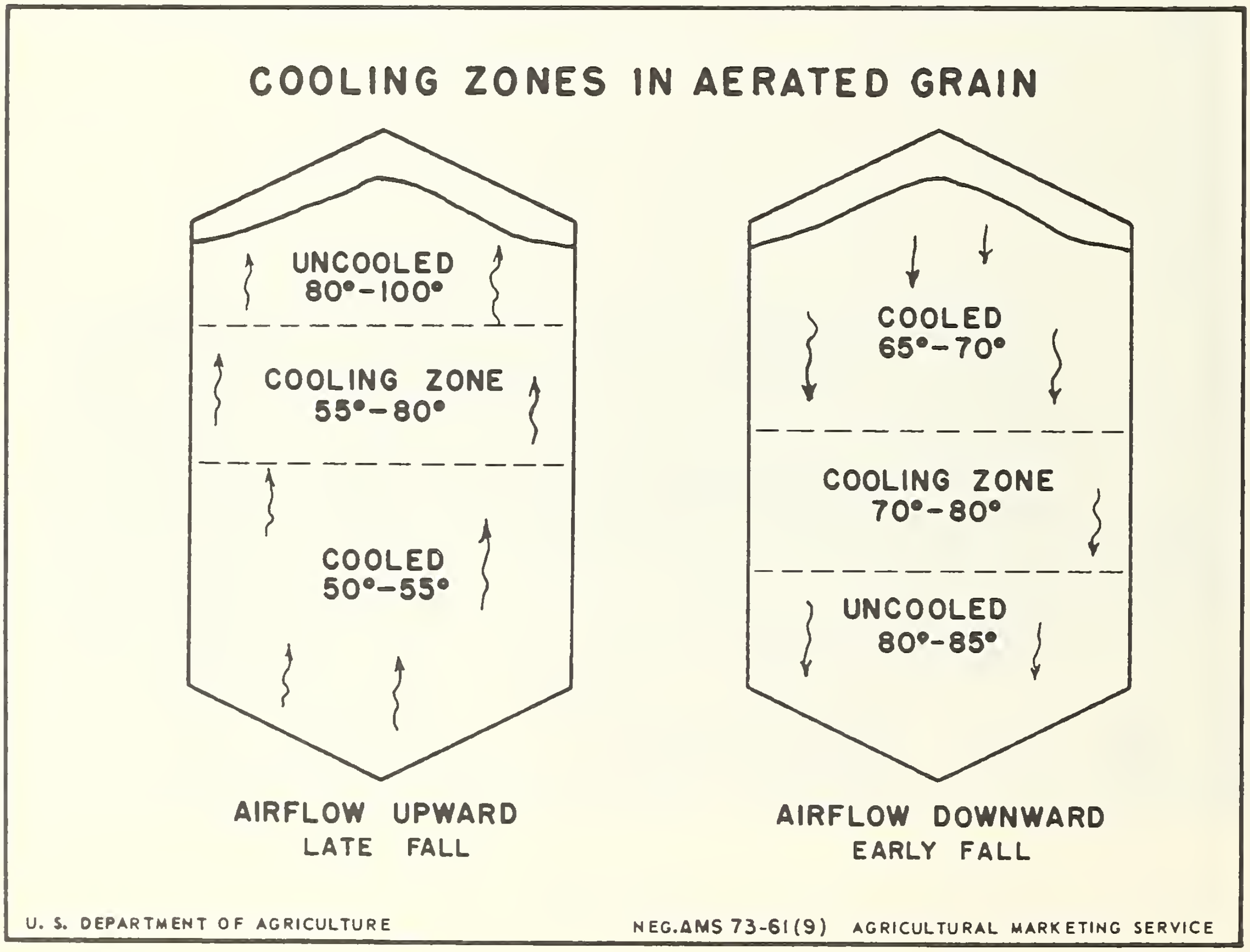

FIGURE 9.—As cool air moves through the grain, the temperature of the grain in front of the cooling zone is unchanged, and the grain behind the zone is almost as cool as the air supplied by the fan.

Southwest, the rate of drying far exceeds the rate of rewetting, and rewetting does not present a problem. The amount of drying, although not great, is significant from the cooling standpoint. For example, the evaporation of 0.1 percent of the moisture in grain can reduce the time required to cool the grain by more than 35 hours. The amount of cooling resulting from evaporation may be 50 percent or more of the total heat removed.

Although cool air entering the grain may have a high relative humidity, it is able to carry away moisture once the temperature of the air has reached that of the grain. When grain temperatures are high, the temperature of the aeration air is raised several degrees and a greater amount of drying is possible. So, grain at 100° F. may be reduced 10 or 15 degrees in temperature in one-half the aeration time required for the same reduction in grain at 50°.

SATISFACTORY GRAIN TEMPERATURES

The temperature to which grain should be cooled depends upon the size and type of storage, the length of time the grain will be held in storage, the possibility of the grain's being moved during warm weather, and the need for insect control. With the usual weather in the Coastal Bend areas of Texas, there is little danger of getting the grain too cold.

The larger the storage structure, the larger is the proportion of grain not directly exposed to the temperature outside the grain mass.

For example, if 230,000 bushels of grain were stored in bins 20 feet in diameter and 40 feet tall (each bin being totally exposed to the air), more than twice the quantity of grain would be subjected to daily temperature changes than if the same quantity of grain were stored in a bin 96 feet in diameter and 40 feet tall. Since smaller diameter bins warm up faster, it may be necessary to cool the grain more in order to maintain desirable temperatures over a prolonged storage period. If tanks are grouped so that the walls are not entirely exposed to outside conditions, the grain warms more slowly, and grain can be held at desirable temperatures later into the summer.

Although there has been some concern over moving cool grain during warm weather, no trouble has been reported in the Southwest from moving grain as cool as 45° F. When moved, this grain was cool enough to cause sweating of drawoff spouts and conveying equipment, but the moisture content was satisfactory when the grain was allowed to reach room temperature before making the moisture determination.

In storing grain through the summer, the greatest problem for the elevator operator is protecting the surface and other areas of the grain mass exposed to the outside air from insects. By keeping the interior of the grain mass cold, the problem is localized in spots where the grain warms to temperatures favorable to insects. In concrete or steel bins, the areas infested with insects usually are at the surface and around the aeration ducts.

Figure 10 shows the average temperatures of grain in several bins, part of which were aerated; the grain in the unaerated bins was turned to maintain quality. Temperatures of unaerated grain were in the range favorable to insects for most of the storage season.

TIME REQUIRED TO COOL GRAIN

The time required to move a cooling zone through a body of grain is dependent on the airflow rate, the type of grain, the amount of foreign material in the grain, the initial temperature of the grain, and the amount of moisture evaporated during aeration.[3]

The higher the airflow rate, the faster the cooling is accomplished. However, because of the resistance of grains to airflow, there is a practical limit to the amount of air that can be supplied for aeration because of power requirements. In tests made in both upright and flat storages, rates of 1/20 to 1/10 cfm per bushel were adequate to cool the grain before undesirable changes took place in the condition of the grain.

In bins where air distribution is unequal, the lowest airflow rate determines the operating time required to cool the grain.

Some grains offer greater resistance to airflow than others. For example, air can move through corn more easily than through grain sorghum. Therefore, a system designed for cooling corn in a relatively short period would not cool grain sorghum in the same length of time.

Cracked kernels and foreign material may restrict the air passage in a grain mass and substantially reduce the movement of air. The airflow in a bin of grain with a total of 10 percent cracked kernels and foreign material was substantially less than in grain with less than 4 percent.

With $\frac{1}{10}$ cfm per bushel, 70 to 100 hours in the summer and 160 to 180 hours in the fall and winter are typical of the fan operation required to cool grain sorghum to near the air temperature. Aeration with 1/20 cfm per bushel required about twice as many hours of operation. For other airflow rates, the time required to cool is inversely proportional to the airflow rate used.[4]

The number of days required for cooling a bin of grain depends upon the number of hours per day suitable for aeration. In the summer or fall in the Southwest, only 4 hours per day may be suitable, and 18 to 20 days are required to cool the grain. Later in the fall and in the winter, more suitable weather for aeration is available, and fewer days are required.

[3] Holman, Leo E. (ed.) Aeration of Grain in Commercial Storages. U.S. Dept. Agr. Mktg. Res. Rpt. 178, 46 pp., illus. Revised November 1960.

[4] See footnote 3.

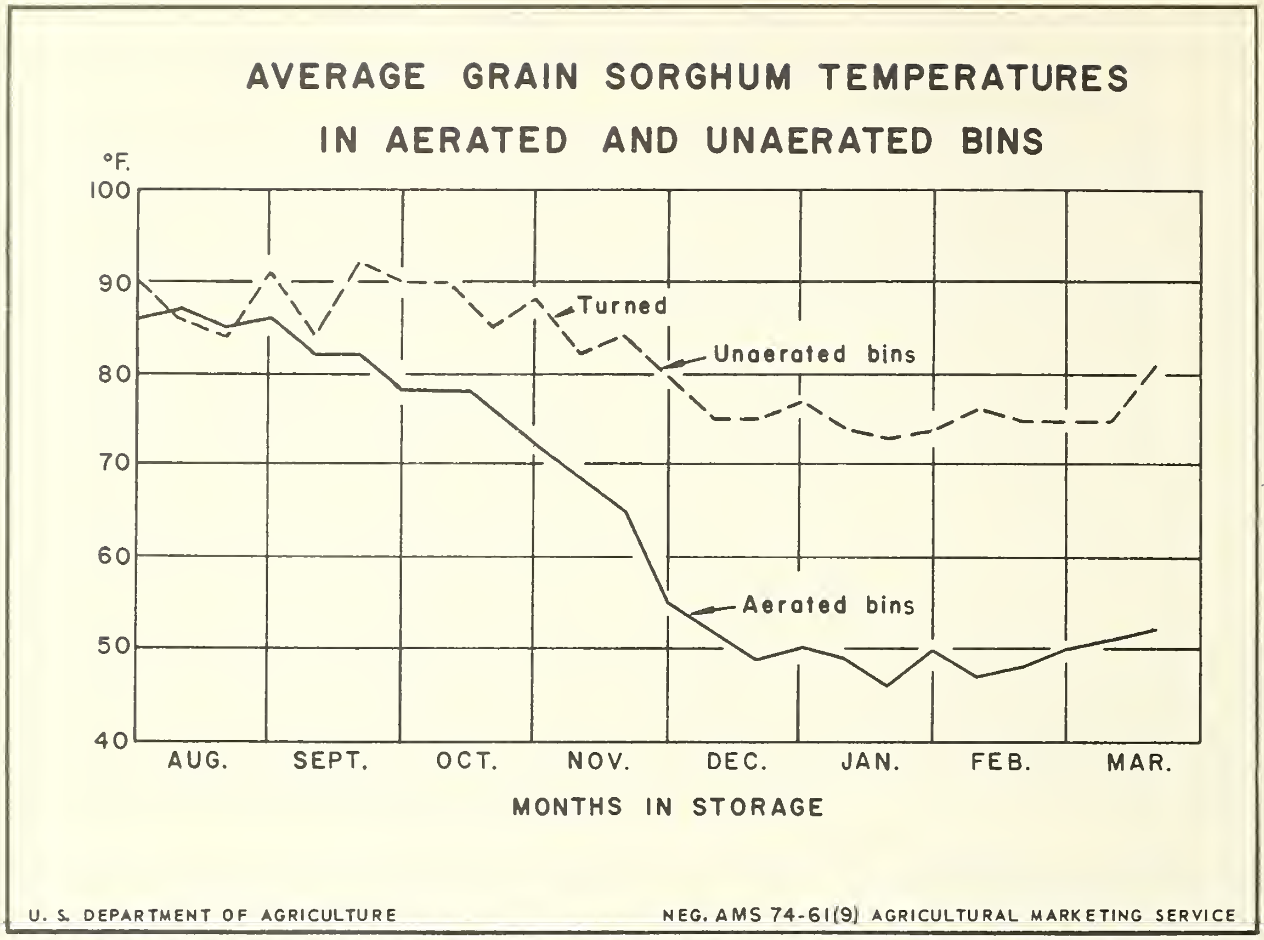

FIGURE 10.—Grain in unaerated bins was turned during storage to maintain its quality; aerated grain was not turned.

USES OF AERATION

An aeration system generally is used for one or more of the following purposes: (1) Holding undried grain until it can be moved through the dryer, (2) removing harvest and dryer heat, (3) removing small amounts of moisture (1 to 2 percent), (4) maintaining the quality of grain during storage, (5) removing odors, (6) distributing fumigant through stored grain, and (7) occasionally for removing dust and providing better working conditions in grain bins.

HOLDING UNDRIED GRAIN

Many elevator operators have found aeration useful for holding undried grain sorghum before moving it through the dryer. This makes it possible to receive grain at a much faster rate. Grain is moved directly from the receiving pit to a holding bin where it is aerated until it can be run through the dryer. Thus, the dryer is put on a regular schedule and dryer operators work regular shifts. Some operators report they can receive an additional 20,000 bushels or more per day by using aeration for holding undried grain.

The fan should be operated continuously regardless of weather until the grain is moved through the dryer. Tests indicated that an airflow of $\frac{1}{20}$ cfm per bushel or more should be used to retard the buildup of molds and to prevent heating. Usually the fan is operated with conventional push-button controls, as weather conditions are not of prime importance for this operation. High-moisture grain (above 16 percent) seldom can be held with aeration for more than 2 weeks without some loss in market quality. The higher the moisture content of the grain, the shorter the holding period should be.

REMOVING HARVEST OR DRYER HEAT

Grain sorghum is harvested during the summer and picks up considerable heat from the sun. The grain warms as it stands in trucks in the field. In some areas of the Southwest, the grain sorghum

received at the elevator is warmer than 100° F. Additional heat may be added if the grain is dried before storing because the grain often leaves the dryer at temperatures well above 110° F.

Aeration has been very effective in removing harvest and dryer heat after the grain has been stored. Thus, the cooling sections of dryers can be bypassed or used as additional drying sections to increase the capacity of the dryer. Cooling the grain in storage can also save an additional pass through the dryer with no heat.

To remove harvest or dryer heat, the fan should be operated continuously until all of the grain is about the same temperature as the outdoor air. A minimum airflow rate of 1/20 cfm per bushel is recommended for the Southwest. No automatic controls are required when aerating for this purpose.

REMOVING SMALL AMOUNTS OF MOISTURE

A moisture content of 13 percent for grain sorghum usually is considered the maximum for safe storage in the sorghum-growing area of Texas. Tests during the years of 1957 through 1959 showed that aeration dried grain sorghum (initially at 15 percent) by about 2 percent during a storage period of from 5 to 7 months. Some commercial operators have, therefore, adopted the practice of storing grain at moistures up to 15 percent. This practice has enabled them to receive grain at a faster rate because grain received with a moisture content of 15 percent or less is not moved through the dryer. It also speeds up the drying rate as wet grain is dried to 15 percent rather than to 13 percent. Aeration should not be depended upon, however, for fast removal of moisture. If grain is to remain in storage only a short time and must meet market requirements, a more rapid method of drying must be used.

When removing small amounts of moisture the fan supplying 1/10 cfm per bushel should be operated continuously for about 20 days. This is the amount of time required to move about five cooling zones through the grain at 1/10 cfm per bushel. After 20 days, automatic controls should be used to operate the fans when the outside air is 10 or more degrees cooler than the grain. Outside air temperatures at night usually are low enough to keep the grain cool and in good condition, but additional operation may be necessary if any tendency toward heating is noted. To provide additional operation, the limit of the automatic control may be raised or a time clock used. As the air becomes cooler in the fall, the operation should be the same as for maintaining the quality of stored dry grain. Airflow rates higher than 1/10 cfm per bushel are advantageous, but the cost of installing systems to furnish the higher airflow may be prohibitive. A rate as low as 1/20 cfm per bushel is risky for this operation, especially if the distribution of air is not uniform.

MAINTAINING QUALITY OF STORED GRAIN

Aeration has almost completely replaced turning as a means of maintaining the quality of stored dry grain. Many of the benefits of aeration can be directly attributed to the cooling of grain. Cooling the grain equalizes the grain temperatures, prevents moisture migration, retards mold growth, and decreases insect activity.

The fan should be operated only when the temperature of the outside air is such that the grain can be cooled 10 or 15 degrees. Grain should be cooled as soon as possible until the grain temperatures range between 40° and 50° F. Several periods of operation are required in the Southwest because of the short duration of suitable outdoor temperatures. A minimum airflow rate of 1/20 cfm per bushel is recommended. Automatic controls are recommended to take advantage of all suitable weather and to provide more efficient operation of the system. Each control setting should cool the grain 10 to 15 degrees.

Cooling To Prevent Moisture Migration

Although grain stored in the Southwest is not subjected to extremely low temperatures, moisture migration is a problem if grain temperatures are above 80° F. during the winter, especially when the grain is stored in concrete or steel grain bins. Aeration has proved effective in maintaining uniform temperatures in the grain and has virtually eliminated spoilage of grain near the walls due to moisture migration. Moisture accumulation near the surface of the grain mass is minor and causes very little spoilage. Apparently any condensation near the grain surface is removed by warm air circulating through the headspace.

Cooling To Retard Mold Growth

Most grain molds grow slowly or not at all below 70° F. when the moisture content of the grain is below 13 percent. Aeration is effective in cooling grain sufficiently to retard mold growth.

Cooling To Decrease Insect Activity

Grain temperatures of 60° F. and below inhibit the reproduction rate of many stored-grain insects. At temperatures of 40° and below, many stored-grain insects become inactive and die from starvation if this level of temperature is maintained long enough. Although cooling cannot be depended upon for full control of insects, it may substantially reduce the bill for fumigants. Insects may infest warm grain near warm walls or surfaces adjacent to warm air. Because insects do not infest the cold interior of the grain mass, surface sprays may be effective in controlling insects and reducing costs for fumigants.

REMOVING ODORS

Grain of good quality and proper moisture content when placed in storage, and aerated prop-

erly, seldom develops objectionable storage odors. In fact, a fresh-grain odor is characteristic of aerated grain. However, grain which has not received proper attention often will develop objectionable odors. Aeration will reduce and often remove some of these odors. Odors caused by more serious deterioration in grain may be changed very little or not at all by aeration.

The amount of fan operation necessary to remove odors varies with storage conditions, extent of deterioration in grain quality, and airflow rate. In some cases, only a few air changes are necessary whereas in other cases much more time is required. If the grain quality is seriously affected, aeration may be of little help in removing odors. A minimum of $\frac{1}{20}$ cfm per bushel is recommended for this operation.

The aeration system should be manually controlled and periodic checks made of the exhaust air to determine the effect of aeration on the removal of odor.

DISTRIBUTING FUMIGANT [5]

Most storage operators in the Southwest have abandoned the practice of turning grain and now rely on aeration systems for fumigating stored grain without turning it. The fumigant is rapidly distributed throughout the grain mass, and usually less fumigant is required than when liquid or granular fumigants are added to the grain as it is turned.

In upright storages the fumigant may be introduced into the airstream in a single pass of air through the grain or it may be recirculated.

With the single-pass method, the fan is operated only long enough to change the air in the bin once. Usually a heavy charge (about $\frac{1}{4}$ to $\frac{1}{3}$ of the requirement) of fumigant is fed into the bin when the fan is first started; then the remainder of the fumigant is metered into the airstream. A fumigant detector is used to determine when the first of the fumigant has moved through the grain mass. Once a sufficient concentration of fumigant is detected leaving the grain, the fan is turned off and the bin is sealed up. For best results and ease of operation, about 10 minutes at an airflow rate of $\frac{1}{20}$ cfm per bushel or 20 minutes at $\frac{1}{40}$ cfm per bushel are desirable for applying the fumigant.

If the fumigant is to be recirculated through the grain, a duct must be connected from the headspace to the fan and all openings tightly closed and sealed. Sometimes an empty bin is used as part of the return duct. With a recirculation system the fumigant is recirculated through the grain until the desired distribution is accomplished. Forcing the air up through the grain usually provides a better distribution with less fumigant loss than drawing it down through the grain.

When insects have been exposed to the fumigant the necessary length of time, the fan is run to remove the fumigant from the storage. The amount of time required to remove the fumigant depends upon the airflow rate, but usually the fumigant can be removed even with low airflow rates in from 2 to 4 hours.

Flat storages are seldom fumigated by the single-pass method. Because air distribution is not uniform, it usually is difficult to get adequate distribution of fumigant without excessive losses. Therefore, the recirculation method is used almost exclusively. A tight building with all ventilators, doors, and joints sealed is essential. Most flat storages which have recently been erected are sealed at the joints with either mastic, felt, neoprene, or rubber. As with the upright storage, better distribution of fumigant with less loss is possible when the fumigant is fed into the airstream with upward movement of air. A heavy charge of fumigant is rapidly fed into the airstream when the fan is first started and then uniformly metered at a slower rate for the remainder of the time allowed for applying the fumigant. Usually 20 to 30 minutes is sufficient if the airflow is adequate. The fumigant is recirculated until an adequate concentration is reached in all points in the grain mass. The operating time required for recirculation after the fumigant is in the system usually is not more than 1 to $1\frac{1}{2}$ hours if the airflow rate is $\frac{1}{40}$ to $\frac{1}{20}$ cfm per bushel. With $\frac{1}{10}$ cfm per bushel, 30 minutes to 1 hour usually is sufficient.

The fumigant is removed from the grain after the exposure period in the same manner as for upright storage.

OPERATING AERATION SYSTEMS

CONTROLLING AERATION FANS

Both manual and automatic controls were effective for operating aeration fans in tests conducted in Texas during 1955 to 1960. The manual control was more effective at installations with a watchman on duty than where no person was available to turn the fans on or off at night or during weekends. Most of the suitable aeration weather was missed if no one was there to start the fans whenever the weather was suitable.

Automatic controls were more effective than manual controls for obtaining the greatest cooling with the least amount of operation. Figure 11

[5] Phillips, G. L., Grain Fumigation, Agr. Chem. X(1): 55–56, 117–121; X(2): 41–43, 133–135, Jan., Feb., 1955.
Phillips, G. L., Experiments on Distributing Methyl Bromide in Bulk Grains with Aeration Systems, U.S. Dept. Agr. AMS–150, 1957.
Phillips, G. L., Experiments on Distributing Liquid Grain Fumigants in Bulk Grains with Aeration Systems. U.S. Dept. Agr. AMS–151, 1957.
Phillips, G. L., Experiments on Distributing HCN in Bulk Grain with Aeration Systems, U.S. Dept. Agr. AMS–152, 1957.

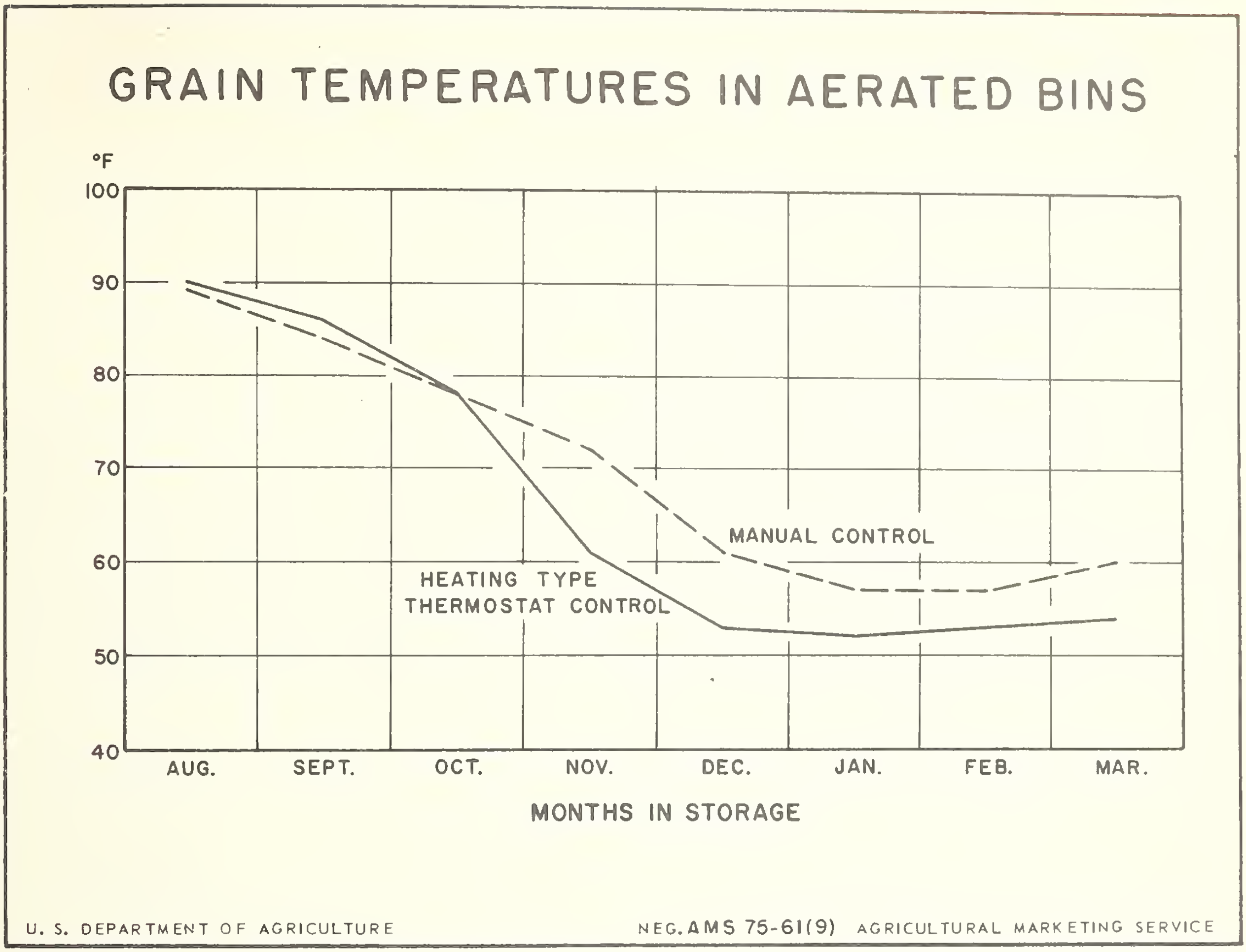

FIGURE 11.—Comparison of temperatures of aerated grain when using manual and thermostat controls.

shows the results of a study in which manual control was compared to thermostatic control. The latter provided lower grain temperatures with about one-half the hours of operation.

Figure 12 represents a study in which three methods of control were compared. Good control was obtained by differential thermostats, conventional heating-type air thermostats, and time clocks.

Humidistats were used in both studies to stop the fans when the relative humidity reached a preset maximum. Results showed that they restricted the operation too severely. Moisture checks on grain that was aerated without regard to the relative humidity of the air showed that humidistats were unnecessary for most systems with airflow rates of 1/20 cfm per bushel or more.

Time clocks are suitable for operating fans a predetermined number of hours each day and at preselected times during the day. It is recommended that the fans run enough hours to complete a cooling stage once a month. For an airflow rate of 1/10 cfm per bushel, 3 hours per day would be required to move a cooling zone through in 1 month during the fall. With 1/20 cfm per bushel, 6 hours per day would be required.

In the tests, a differential thermostat provided good control of the fan. The fan operated whenever the difference in temperature between the high-limit and low-limit sensing bulbs exceeded a predetermined differential setting, regardless of the level of the temperature. The bulbs were placed as follows for upward and downward movement of air:

Direction of air movement and type of bulb	*Location of sensing bulb*
Upward:	
High-limit bulb	3 feet below grain surface and 3 feet from wall.
Low-limit bulb	Shady location in outdoor air
Downward:	
High-limit bulb	3 feet above floor and 3 feet from wall.
Low-limit bulb	Shady location in outdoor air

These arrangements provided the coolest grain with the least amount of aeration of all the methods studied. A setting with a 15-degree difference between the bulbs cooled the grain 10 degrees and saved considerable fan operation.

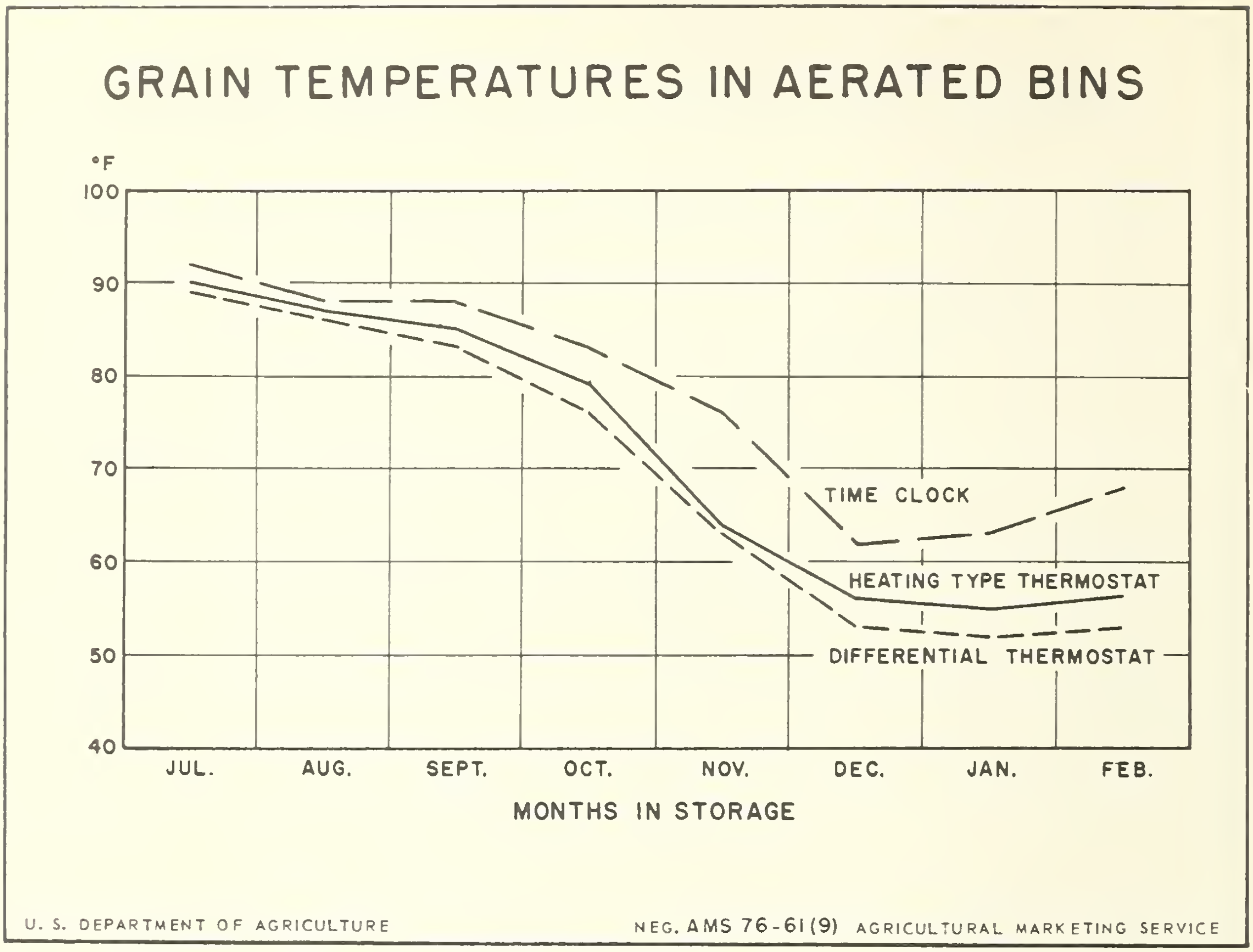

Figure 12.—Comparison of temperatures of aerated grain when using a time clock, heating type thermostat, and differential thermostat for controlling fan operation.

OPERATING SCHEDULES

Although the average monthly air temperatures during the storage season in the Southwest are higher than the desired grain temperatures, a considerable amount of cooling can be accomplished by using recommended control settings and operating schedules. Table 1 shows the recommended control settings for three areas in Texas with the approximate number of hours of fan operation required per setting at 1/10 cfm per bushel for different periods during the year to obtain the expected cooling. This table is based on U.S. Weather Bureau climatological data. The schedules are applicable for other areas in the Southwest with similar weather conditions.

For most operation in central and south Texas, low-limit thermostats and humidistat controls are unnecessary. However, the fans should be stopped if rain or fog persists for more than 6 hours.

In west Texas, a low-limit thermostat may be necessary if the fans are not attended for long periods. Because of more severe weather in west Texas, there is some chance of cooling grain below the desired temperature range of 40° to 50° F.

Automatic controls must be kept in good working order and set properly to be effective. Time clocks must be reset each time the electrical service to the clock is interrupted. Conventional high-limit thermostats must be reset each time a cooling stage has been completed under a particular setting to avoid unnecessary operation. A humidistat must be given frequent attention to insure proper functioning. Humidistats with hair elements frequently lose their calibration. A differential thermostat once set requires little attention or adjustment.

A typical system in the central and south Texas areas consists of a high-limit thermostat and an elapsed time recorder. In west Texas, a low-limit thermostat should be connected in series with the high-limit thermostat for winter aeration. A typical control circuit for controlling fans in central and south Texas is shown in figure 13.

Table 1.—*Recommended setting for control of fans, expected range in grain temperatures after aeration, and approximate hours of fan operation*[1]

Period and area	Control set to operate fans when air temperature is—	Expected range in grain temperatures	Approximate operation time per setting[2]
	° *F.*	° *F.*	*Hours*
South Texas:			
June through September 15	Below 80	75 to 85	80
September 15 through November 15	Below 65	60 to 70	120
November 15 through February	Below 50	45 to 55	160
March through June[3]	Below 70	65 to 75	120
Central Texas:			
June through August	Below 80	75 to 85	80
September through October	Below 70	65 to 75	120
November through February	Below 45	40 to 50	160
March through April[4]	Below 60	55 to 65	120
West Texas:			
June through August	Below 75	75 to 80	80
September through October	Below 65	60 to 70	120
October through February	Below 45	40 to 50	160
March through June[4]	Below 60	55 to 65	120

[1] Airflow rate, 1/10 cfm per bushel.
[2] Thermostats must be reset after each cooling stage to avoid unnecessary operation of fans.
[3] No operation for cooling is recommended if grain temperature is below 75° F.
[4] No operation for cooling is recommended if grain temperature is below 65° F.

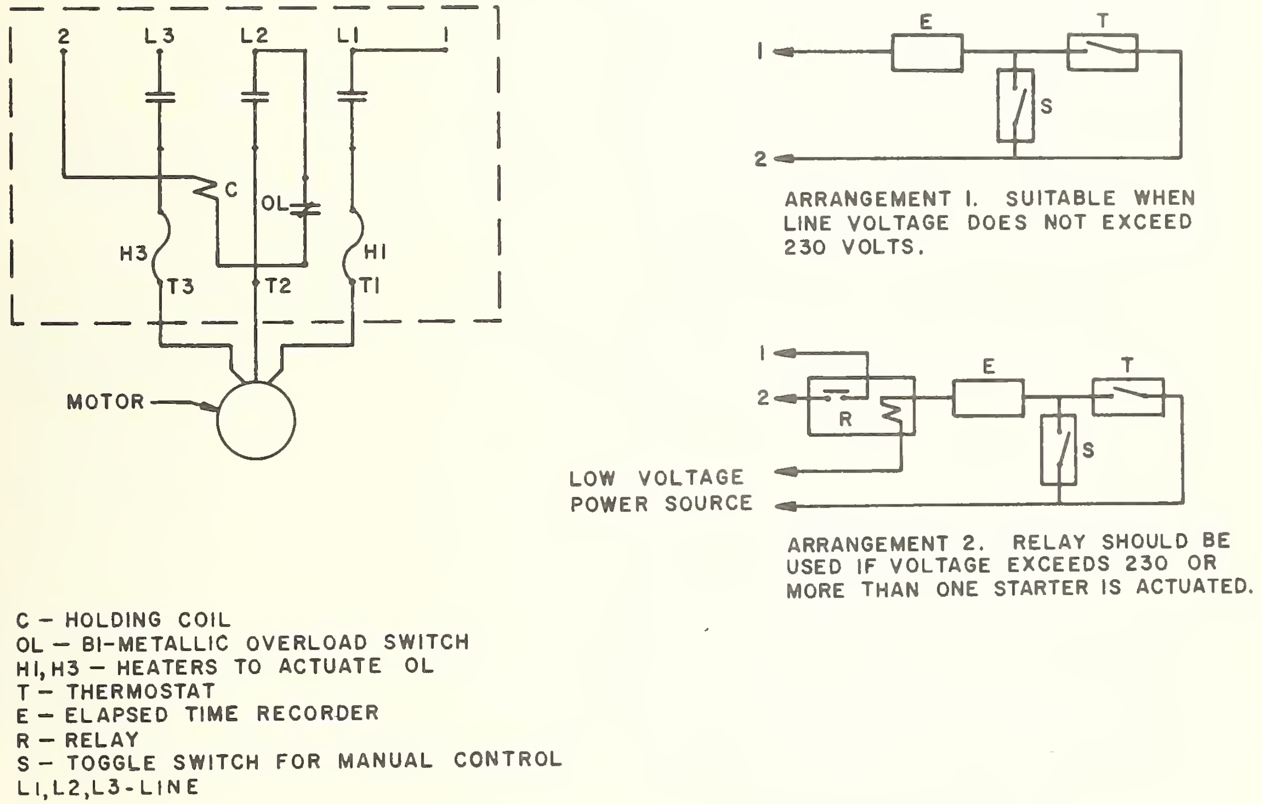

Figure 13.—A typical control circuit for operating aeration fans.

Control elements should be surrounded by air in the same condition as that being supplied to the grain. They should be located away from excessively dusty or windy locations. A well-ventilated enclosure made of a poor heat-conducting material and placed in a shady location should be used to house the controls.

DIRECTION OF AIRFLOW

Generally, aeration systems are designed to move air downward through the grain and discharge it at the bottom. However, there are some advantages to moving the air upward or across the bin.

The advantages of top to bottom movement are: (1) Condensation in the surface layers of grain and on the ceiling is prevented; (2) objectionable odors can be easily detected by checking the exhaust air from the fan; and (3) heat from the fan or motor is not transferred to the grain.

The following are the advantages of moving the air from bottom to top: (1) Less operating time is required to remove the heat from the grain at the time it is placed in storage. (2) Any heat accumulating under exposed roofs can be moved out without moving it through the grain mass. (3) It is possible to take advantage of any ground cooling. (4) It is easier to determine when a cooling zone has passed through a grain mass. (5) The pattern of cooling between aeration ducts is better. (6) There is better distribution of air with long aeration ducts. (7) The fans usually are more efficient when the exhaust of the fan is connected to the duct system. (8) It usually is less expensive to connect the exhaust side of a centrifugal fan to a duct system because the exhaust generally is smaller than the intake. (9) Better results are obtained when the fumigant is inserted at the bottom of the grain mass and moved to the top.

A considerable number of aeration systems which move air across the bin were installed in the Southwest in 1960 (fig. 14). The biggest advantage of this type of system is a sizable saving in the cost of power. Other advantages are that higher airflow rates are possible; less expensive fans can be used; and aeration can be installed in bins where conventional-type systems are less practical.

The disadvantages of the crossflow systems are: (1) The initial cost usually is higher than the cost for conventional-type systems. (2) The system is more difficult to design and install. (3) A more elaborate and expensive valve system must be built where partially filled bins are to be aerated. (4) There is some danger from condensation in the exhaust duct. This condensation may cause spoilage in the lower part of the bin unless the grain is turned and blended after the aeration, or some means of preventing the condensation in the duct are provided.

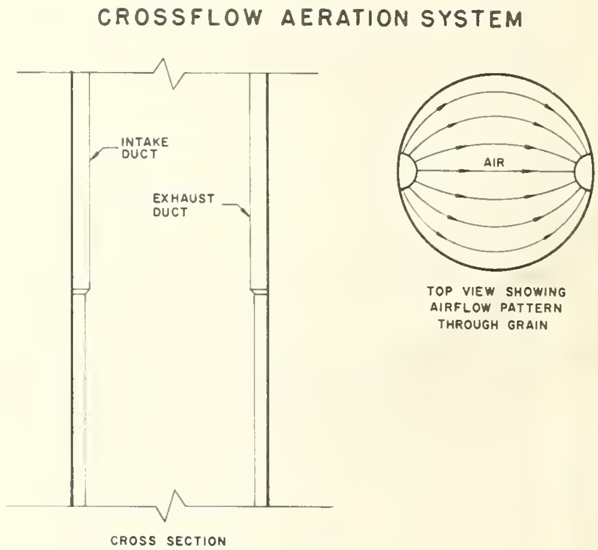

Figure 14.—With crossflow aeration the air moves sideways through the grain instead of vertically. Thus higher airflow rates are possible with less horsepower in upright storages.

OPERATING COSTS

Cost of operating an aeration system seldom becomes a major item in the management of a grain storage if the system is well planned and operated as recommended for the area and the type of grain aerated.

Three cooling stages usually are required for best results in the Southwest. The cost of electricity for three-stage cooling of grain sorghum, as computed from research tests and industry experience, is shown below:

	Cent per bushel
Flat storage	0.16
Oil tank storage	.13
Upright storage	.20

Power costs for each stage of cooling for a system will vary in proportion to the amount of time required to complete the cooling in any season (table 1).

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